

**Summarized Background Information
for the ORD Empirical Model to Predict Styrene Emissions
from Fiber-Reinforced Plastics Fabrication Processes**

This background information represents selected sections excerpted from a journal article entitled “Empirical Model to Predict Styrene Emissions from Fiber-Reinforced Plastics Fabrication Processes” to be published in the Journal of the Air & Waste Management Association.

DESCRIPTION

The Air Pollution Prevention and Control Division (APPCD) of the Environmental Protection Agency's (EPA) National Risk Management Research Laboratory (NRMRL), in cooperation with Research Triangle Institute (RTI), developed an empirical model to predict emissions from open molding FRP fabrication processes. This model is of the following form:

$$EF = EF_b @ (MF)_1 @ (MF)_2 \dots @ (MF)_k$$

where:

EF = Emission factor, as a percentage of the styrene in the gel coat or resin.

EF_b = Baseline emission factor; i.e., the emission factor from a process under fixed, typical operating conditions.

$(MF)_{1, 2, \dots, k}$ = Applicable modification factors, which are based on changes in parameters known to affect styrene emissions (gel time, styrene content, thickness, etc.).

This modeling approach was simplified by the introduction of baseline emission values for each process. The baseline emission values were calculated under fixed, typical operating conditions. If all the conditions at a particular plant were equal to baseline conditions, each of the modification factors would be given a value of 1.0, and the predicted emissions would equal the baseline value. An overall emission factor is then determined by the product of each independent modification factor. The model assumes that the effect of each modification factor is independent from those of the others. This assumption may introduce errors, especially when conditions result in nearly all calculated modification factors being substantially above or below 1.0. Data from seven emission studies were evaluated and used as model inputs (see Table 1).

Baseline values in Table 2 for gel coating and resin sprayup were derived from an EPA/RTI study.¹ In this study, “dry-material-off-mold” (i.e., material that misses the mold, falls on the floor, and dries there) was measured to complete the material balance. Dry-material-off-mold was found to be an important parameter in modeling styrene emissions.

Due to the limited number of studies, an assumption was made that all types of resins (orthophthallic, dicyclopentadiene [DCPD], vinyl ester, etc.) have the same level of emissions for a given styrene content.

Example Calculations

The following example is based on the gel coating thickness modification factor and illustrates how various modification factors were developed:

- 1) Composites Fabricators Association (CFA) testing in October 1995,² indicated an average emission factor of 56.2% AS for a gel coat thickness of 18 mils (0.018 in.), and an emission factor of 47.5% AS for a gel coat thickness of 24 mils.

- 2) A gel coat thickness of 20 mils was chosen as the baseline. The choice of 20 mils is somewhat arbitrary, but is believed to represent a typical thickness for a single application layer within the FRP industry. Using linear interpolation between the two laminate thicknesses, the emissions for a laminate thickness of 20 mils would be 53.3% AS.
- 3) If the resin sprayup emission factor for 24 mils is 47.5% AS, and the emission factor for the baseline 20 mils is 53.3% AS, the modification factor for 24 mils is $47.5/53.3$, or 0.891. Similarly, the modification factor for 18 mils is $56.2/53.3$, or approximately 1.055.
- 4) The equation for a straight line passing through modification factors of 1.055 at 18 mils and 0.891 at 24 mils is $y = 1.546 - 0.0273x$, where x = gel coat thickness in mils.

A sample calculation for emissions from gel coat spraying, with a thickness of 25 mils, and all other conditions equal to those of the gel coating baseline, is presented in Table 3. The calculated emission rate in Table 3 is 47.1% AS, which is considerably higher than the AP-42 range of 26-35% AS.

Modification Factors Equations

Ten parameters that influence styrene emissions are included in the model. To quantify the impact of these parameters, modification factors equations shown in Table 4 were developed based on various studies (see Table 1). Some of the parameters that influence styrene emissions are discussed below.

Neat Styrene Content

Background data related to the neat styrene content modification factor are shown in Figure 1. Neat refers to the styrene content (% by weight) before filler is added. The second order modification factor quadratic equation is also shown. This type of curve is probably more accurate than a linear regression in describing emissions behavior at low styrene contents (below 33% styrene). A linear regression fitted through the data would result in prediction of negative emissions at very low styrene contents, which is obviously a physical impossibility. Figure 1 illustrates that styrene content is predicted to have a large effect on emissions in resin sprayup. For example, the modification factor for a neat styrene content of 38% is 1.0, but the modification factor for a neat styrene content of 42% is 1.21; in other words, emissions (expressed as % AS) are predicted to increase by 21% when the styrene content is raised 11%, from 38 to 42%.

Background data used to generate the styrene content modification factor equation for gel coat spraying are from a test EPA/RTI conducted in June 1995¹, and the CFA Phase I testing³. The resulting modification factor equation is a second order quadratic equation, $y = 0.55 + 0.011x + 0.00002x^2$. The predicted effect of styrene content on gel coat emissions is much less than on resin sprayup emissions.

Air Velocity

The predicted effect of air velocity over the mold is depicted in Figure 2. It can be seen that air velocity over the mold has little effect on emissions for air velocities in the range from 50 to 200 ft/min. This result is based on the same tests^{1,3} mentioned earlier.

Figure 2 shows that reductions in air velocity (for air velocities below approximately 40 ft/min) are predicted to produce reductions in emissions. For air velocities near zero (i.e., no air exchange, as

could be found in an enclosed space), the predicted emission reduction is up to 36% (a modification factor of 0.64), relative to emissions at 100 ft/min. Data for air velocities below 40 ft/min are available from a test⁴ conducted by the Society of the Plastics Industry/Pultrusion Industry Council (SPI/PIC) and a bench-scale test conducted by RTI which measured curing emissions from paint lids. Model predictions for air velocities below 40 ft/min are based on the average values of these two tests. Figure 2 shows that the model predictions below 40 ft/min have a great deal of uncertainty which is caused by the wide variation in results of these two tests. Further, neither of these tests represented resin sprayup or gel coating processes because spray guns were not used to apply the resin material. Therefore, it may be inappropriate to extend the results to sprayup or gel coating. However, it is reasonable to expect some reduction in emissions at very low velocities, because a reduction in “refresh rate” over the part surface tends to reduce evaporation rate.

Dry-Material-Off-Mold

Operator spraying technique appears to have a significant effect on emissions from gel coat and resin sprayup. The challenge is to develop methodologies that can help quantify and correlate the operator spraying technique with styrene emissions. In the summer of 1995, EPA and RTI conducted tests^{1,5} that demonstrated that emissions could be correlated with transfer efficiency, which relates to operator spraying technique. In these tests, transfer efficiency was defined as the amount of wet material on the mold immediately after spraying stopped divided by the total amount of material sprayed. However, it would be very difficult to measure transfer efficiency, especially with large molds in a production situation, since the mold would have to be placed on a high-accuracy, high-capacity scale. During these tests, the amount of dry-material-off-mold was also measured, which relates to both transfer efficiency and operator spraying technique. The amount of dry-material-off-mold, a much easier measurement than the amount of wet-material-on-mold, also correlated with styrene emissions. The ratio of the amount of dry-material-off-mold and the amount of material sprayed was then used as a model input.

The modification factor for the dry-material-off-mold for resin sprayup was developed using data from the testing that EPA/RTI conducted in 1995¹ for both controlled and normal spraying. During controlled spraying, the mass of dry-material-off-mold averaged 5.7% of the total material sprayed. For the normal resin sprayup, the mass of dry-material-off-mold represented 15.7% of the total material sprayed.

At present, no tests have been conducted to quantify the amount of dry-material-off-mold for large female parts such as boat hulls, though both CFA³ and NMMA⁶ measured their emissions. However, spraying large female molds can be assumed to generate significantly less dry-material-off-mold than spraying small (25 ft²) male molds, which were used during EPA/RTI tests.¹ The emissions of tests conducted by CFA³ and NMMA⁶ were not substantially lower than those measured during the EPA/RTI tests. Therefore, the model modification factor equation for dry-material-off-mold is a curve ($y = 0.90 + 0.0007x + 0.0025x^2$) that reaches a minimum at approximately 10% lower than the value measured during EPA/RTI tests.¹

The modification factor equation for the dry-material-off-mold gel coat spraying is $y = 0.862 + 0.023x$. This modification factor equation was derived from the results of the EPA/RTI test¹ using both controlled (emission factor of 54.2% AS and dry-material-off-mold of 6.4% of the total material

sprayed) and normal (emission factor of 62.5%AS and dry-material-off-mold of 13.1% of the total material sprayed) gel coat spraying.

Distance from Spray Gun to Mold

Another parameter reflecting operator spraying technique that appears to have an effect on emissions is the distance from the spray gun to the mold. Two sources of data were used to develop the distance-from-spray-gun-to-mold modification factor. One source is a study conducted by the CFA in 1996³ which used a variety of mold sizes and shapes. Tests were conducted using both controlled and uncontrolled spraying. During controlled spraying, the spray gun was held approximately 12 in. from the mold and maintained perpendicular to the mold surface. In uncontrolled spraying, the spray gun was held approximately 19 in. from the mold surface and allowed to have an angle of up to 45E from the mold surface. Analyzing the CFA data, based on these distances and angles, an average distance from the spray gun to the mold surface of approximately 23 in. was assumed. This assumes that approximately half of the total time was spent spraying perpendicularly from a distance of 19 in., and half of the total time was spent spraying at a 45E angle from 19 in., which produces a distance of 27 in. However, during these controlled and uncontrolled spraying comparisons, spray gun pressure was also varied, with higher pressures used during the uncontrolled testing. Therefore, the effect of distance may be compounded by comparing controlled with uncontrolled test results in this study since a new variable was introduced. Another source of data in Figure 3 is a study conducted by CFA in February 1997.⁷ In this study, a gun was held in a stationary position perpendicular to a mold at fixed distances of 12, 24, and 36 in. from the mold. The peak exhaust concentration was measured at each distance. Although peak exhaust concentrations during spraying do not necessarily correlate with spraying emissions, the data from this study are included in Figure 3 because the distance from the spray gun to the mold was carefully controlled.

A final set of data in Figure 3 are based on results of a study that NMMA conducted of emissions from laminating 18- and 28-ft hulls. When laminating the 28-ft hull, the spray gun was, on average, farther from the mold than during spraying of the 18-ft hull. This greater distance produced higher emissions. The modification factor equations for distance-from-the-mold are based on fitting these NMMA results alone. This is due to the problems in assessing the CFA results, as described in the preceding paragraph..

Another parameter, not included in the model, but shown to have an effect on styrene emissions is the spray gun tip pressure/tip size as demonstrated by the CFA optimization study conducted in 1996.³ The study showed that, for any given tip size, increasing tip pressure increases emissions. This parameter was not included in the model because its effect was found to interact with controlled spraying technique. For example, during this resin sprayup optimization study, controlled spraying was found to reduce emissions (expressed in % AS) by 21% relative to baseline conditions. Also, the optimizing spray gun pressure was found to reduce emissions by 9% relative to baseline conditions. However, when controlled spraying and optimized spray gun pressure were both used, the emission reduction was still approximately 21%. This emission reduction is equivalent to the reduction produced by controlled spraying alone.

Temperature and Thickness

Air temperature can have a great impact on styrene emissions, especially when FRP facilities do not have air conditioning. In some locations, summer temperatures can be above 95EF, which may result in a significant increase in styrene emissions. In the model, the air temperature modification factor changes by approximately 1% for every 1EF above or below the baseline of 75EF. But, if plant air temperature were maintained within ± 5 EF of 75EF, this parameter would be of little significance.

Other modification factors are important for only certain processes. For example, thickness has a very significant effect on the percentage available styrene emitted for gel coating, but has much less significance for resin sprayup at typical thicknesses.

REFERENCES

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2. Haberlein, R.A. Derivation and Verification of the CFA Emission Models, Presented Strum, M., U.S. EPA, Office of Air Quality Planning and Standards, September 18, 1997.
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6. Stelling Engineering, *Baseline Characterization of Emissions from Fiberglass Boat Manufacturing for National Marine Manufacturers Association*, August 1997.
7. Craigie, L., Dow Chemical Company, memorandum to Strum, M., U.S. EPA, Office of Air Quality Planning and Standards, dated June 27, 1996.

Figure Captions

Figure 1. Modification factor for initial styrene content during resin sprayup.

Figure 2. Background data for air velocity modification factor.

Table 1. Emission Studies Used as Model Inputs.

Model Parameter	Emission Studies Used as Input to Model						
	1	2	3	4	5	6	7
Baseline Emission Factors							
Resin sprayup		5-1					
Gel coat spraying		6-1					
Hand layup (with bucket/paint roller)	20-1						
Flow coating			2-1				
Pressure-fed rolling			1-1				
Modification factors							
Styrene content for sprayup	20-2	24-2		26-16			
Styrene content for hand layup, pressure-fed rolling, flow coating	20-2						
Styrene content for gel coat spraying	20-2	18-2					
Distance from spray gun to mold							8-2
Dry-material-off-mold, as a percentage of total material sprayed		12-2					
Laminate/gel coat thickness	40-4	12-2					
Cup gel time	40-4						
Application rate	40-2						
Air temperature						18-2	
Air velocity (above 40 fpm)	40-2	12-2					
Air velocity (below 40 fpm)					3-3		
Styrene suppressant		11-3		10-2			

Note: Numbers indicate test runs and test conditions. For example 20-2 indicates 20 test runs, at 2 test conditions.

Emission studies:

- Study 1. CFA/Dow Phase I⁵
- Study 2. EPA/RTI Pollution Prevention (EPA, 1997)³
- Study 3. CFA/Dow Phase II⁴
- Study 4. EPA/RTI Filled Resin⁷
- Study 5. Pultrusion Industry Council Phase II⁶
- Study 6. Dow Filament Winding⁹
- Study 7. NMMA Boat Manufacturing⁸

Table 2. Chosen Baseline Values and Baseline Conditions

Process	Gel Coating	Resin Sprayup	Hand Layup	Pressure-Fed Roller	Flow Coater (with chop)
Baseline emission value (%AS)	54.8	18.9	12.3	12.6	11.3
Styrene content, neat (% , by weight)	38	38	38	38	38
Styrene suppressant	N/A (a)	No	No	No	No
Distance from spray gun to mold (in.)	15	15	N/A	N/A	15
Dry-material-off-mold, as a percentage of total material sprayed (%)	6	6	N/A	N/A	N/A
Thickness (0.001 in.)	20	70	70	70	70
Gel time (minutes)	15	15	15	15	15
Application rate (lb/min)	2	4	N/A	N/A	N/A
Air temperature (EF)	75	75	75	75	75
Air velocity (ft/min)	100	100	100	100	100

N/A = Not Applicable

- (a) Not enough data were available to develop a modification factor for this parameter. Normally, gel coats do not come with styrene suppressant, except some used for the interior of boats.

Table 3. Example Calculation (gel coat spraying)

Parameter	Value	Modification Factor	
		Equation ^a	Calculated Value
Styrene content (% by weight)	38	$0.553 + 0.011x + 0.00002x^2$	1.00
Distance from spray gun to mold (in.)	15	$0.868 + 0.00088x$	1.00
Dried-material-off-mold/total material sprayed (%)	6	$0.862 + 0.023x$	1.00
Laminate/gel coat thickness (mils; i.e., thousandths of an inch) ^c	25	IF $x < 40$: $1.546 - 0.0273x$; IF $x \geq 40$: $3.34 - 0.0583x$	0.86
Cup gel time (min)	15	$0.97 + 0.002x$	1.00
Application rate (lb/min)	4	1	1.00
Air temperature (EF)	75	$0.175 + 0.011x$	1.00
Air velocity (ft/min)	100	IF $x < 38$: $0.64 + 0.0088x$; IF $x \geq 38$: $0.96 + 0.000405x$	1.00
Baseline value (%AS)			54.8
Overall modification factor			0.86
Calculated emissions (%AS)			47.1 ^b

^a In equations, x denotes the value for the applicable parameter.

^b The AP-42 emission factor range for gel coating 26-35 %AS.

Table 4. Modification Factors for Styrene Emission Factor Prediction Model

Parameter	Units for x	Modification Factor Equation for Gel Coating	Modification Factor Equation for Resin Sprayup	Modification Factor Equation for Hand Layup, Pressure-Fed Roller, Flow Coater
Neat resin styrene content	%	$0.553 + 0.011x + 0.00002x^2$	$0.003x + 0.000614x^2$	$0.24 + 0.02x$
Styrene suppressant	YES/NO	Not applicable	IF NO: 1.00; IF YES: $0.64 + 0.005y$ (a)	IF NO: 1.00; IF YES: $0.50 + 0.005y$ (a)
Distance from spray gun to mold	in.	$0.868 + 0.0088x$	$0.692 + 0.0205x$	1 (b)
Dry-material-off-mold/total material sprayed	%	$0.862 + 0.023x$	$0.906 + 0.0007x + 0.0025x^2$	Not applicable
Thickness (c)	mils	IF $x < 40$: $1.546 - 0.0273x$; IF $x \geq 40$: $0.492 - 0.0009x$	IF $x < 40$: $3.34 - 0.0583x$; IF $x \geq 40$: $1.14 - 0.002x$	IF $x < 40$: $3.34 - 0.0583x$; IF $x \geq 40$: $1.63 - 0.009x$
Cup gel time	min	$0.97 + 0.002x$	$0.97 + 0.002x$	$0.79 + 0.014x$
Application rate	lb/min	1	IF $x < 4$: $1.408 - 0.102x$ IF $x \geq 4$: 1.0	Not applicable
Air temperature	EF	$0.175 + 0.011x$	$0.175 + 0.011x$	$0.175 + 0.011x$
Air velocity over mold	ft/min	IF $x < 38$: $0.64 + 0.0088x$; IF $x \geq 38$: $0.959 + 0.000405x$	IF $x < 38$: $0.64 + 0.0088x$; IF $x \geq 38$: $0.959 + 0.000405x$	IF $x < 38$: $0.64 + 0.0088x$; IF $x \geq 38$: $0.959 + 0.000405x$

Notes:

- (a) In modification factor for resin spraying with styrene suppressant, y represents amount of filler (by weight), in the resin, as applied. For example, sprayup of a styrene-suppressed resin with 50% filler (by weight, as applied) would have styrene suppressant modification factor of 0.89.
- (b) Only applies to flow coater.
- (c) Thickness refers to the thickness for one laminating session, which might include 2-4 passes with the spray gun.

DATA USED FOR THE ORD MODEL DEVELOPMENT

Baseline Emission Factors

Dry Mat'l efficiency M.F.	Thickness (mils)	Thickness M.F.	Gel time (minutes)	Gel time M.F.	Application rate (lb/min)	Application rate M.F.	Air temp. (F)	Air temp. M.F.	Air velocity (ft/min)	Air velocity M.F.
0.987	95	0.950	20	1.010	5.32	1.000	73	0.983	49	0.980
0.995	70	1.000	15	1.000	4	1.000	75	1.005	100	1.001
1.038	19.98	1.001	17	1.004	1.73	1.000	73	0.9752	86	0.995
1.000	20	1.000	15	1.000	2	1.000	75	0.998	100	1.001
1.000	64.5	1.049	22.5	1.105	Not Appl.	1.000	75	1.005	75	0.991
1.000	70	1.000	15	1.000	Not Appl.	1.000	75	1.005	100	1.001
1	80.0	0.911	15	1.000	Not Appl.	1	75	1.005	100	1.001
1	70.000	1.000	15	1.000	Not Appl.	1	75	1.005	100	1.001
1	80	0.911	15	1.000	Not Appl.	1	75	1.005	100	1.001
1	70.000	1.000	15	1.000	Not Appl.	1	75	1.005	100	1.001

Styrene Content for Sprayup

CFA Phase I testing, resin spray-up	Description	Initial styrene content (%)	Emissions (% AS)	Emissions (relative to 38% content)
Low styrene	Average	35	19.86	0.818
High styrene	Average	42	30.18	1.243
Calculation for 38% styrene	Calculation	38.000	24.283	1.000
EPA/RTI testing, June 1995 , resin sprayup	Description	Initial styrene content (%)	Emissions (% AS)	Emissions (relative to 38% content)
Low styrene (35.3%)	30 minute gel	35.3	17.65	1.01
Calculation for 35.3%, 20 minute gel	20 minute gel	35.3	17.307	0.99
RF1-Low profile baseline	20 minute gel	38.3	17.5	1.00
Calculation for 38% styrene	Calculation	38.000	17.481	1.00
EPA/RTI filled resin testing, resin R1	Description	Initial styrene content (%)	Emissions (% AS)	Emissions (relative to 38% content)
R1 - Ortho, w/supp, 12 min gel	F5 - Run 28	50.9	16.00	2.00
R1	F3 - Run 13	43.7	10.20	1.28
R1	F3 - Run 14	43.7	10.20	1.28
R1	F2 - Run 3	41.9	12.20	1.53
Calculation for 38% styrene	Calculation	38	8.00	1.00
EPA/RTI filled resin testing, resin R2	Description	Initial styrene content (%)	Emissions (% AS)	Emissions (relative to 38% content)
R2 - DCPD, w/supp, 12 min gel	F6 - Run 7	38.8	15.30	0.98
R2	F5 - Run 30	40.1	16.20	1.04
R2	F5 - Run 31	40.1	15.90	1.02
R2	F4 - Run 21	38	16.50	1.06
R2	F4 - Run 22	38	17.80	1.14
R2	F3 - Run 1	32.2	13.10	0.84
R2	F3 - Run 2	32.2	11.70	0.75
R2	F2 - Run 11	31.7	10.60	0.68
R2	F2 - Run 12	31.7	10.30	0.66
R2	F1 - Run 26	31.4	10.90	0.70
Calculation for 38% styrene	Calculation	38	15.60	1.00
EPA/RTI filled resin testing, resin R3	Description	Initial styrene content (%)	Emissions (% AS)	Emissions (relative to 38% content)
R3 - DCPD, w/o supp, 12 min gel	F4 - Run 4	36.8	17.70	0.96
R3	F3 - Run 5	31.6	14.60	0.79
R3	F3 - Run 6	31.6	13.90	0.75

Calculation for 38% styrene	Calculation	38	18.50	1.00
EPA/RTI filled resin testing, resin R4	Description	Initial styrene content (%)	Emissions (% AS)	Emissions (relative to 38% content)
R4 - DCPD, w/supp, 6 min gel	F6 - Run 9	38.4	14.00	0.90
R4	F6 - Run 10	38.4	12.90	0.83
R4	F4 - Run 15	37.7	17.90	1.15
R4	F4 - Run 16	37.7	17.80	1.15
R4	F3 - Run 23	32.5	12.70	0.82
R4	F3 - Run 24	32.5	11.20	0.72
Calculation for 38% styrene	Calculation	38	15.50	1.00
EPA/RTI filled resin tesing, resin R5	Description	Initial styrene content (%)	Emissions (% AS)	Emissions (relative to 38% content)
R5 - DCPD, w/supp, 6 min gel, BPO cat	F3 - Run 18	45.4	12.00	1.50
R5	F3 - Run 19	45.4	12.40	1.55
R5	F2 - Run 17	47.5	13.40	1.68
Calculation for 38% styrene	Calculation	38	8.00	1.00

Styrene Content for Hand Layup

Initial styrene content (%)	Emissions (% AS)	Emissions (relative to 38% content)
35	13.52	0.94
42	15.66	1.08
38.000	14.438	1.00

Styrene Content for Gel Coating

CFA Phase I testing, gel coating	Description	Initial styrene content (%)	Emissions (% AS)	Emissions (relative to 38% content)
Low styrene	Average	35	49.00	0.94
High styrene	Average	40	54.08	1.04
Calculation for 38% styrene	Calculation	38.000	52.049	1.00
EPA/RTI testing, June 1995, gel coating	Description	Initial styrene content (%)	Emissions (% AS)	Emissions (relative to 38% content)
Low styrene (25.4%)	27 minute gel	25.4	54.2	0.98
Calculation for 25.4%, 17 minute gel	17 minute gel	25.4	47.448	0.85
GF1-Regular gel coat	17 minute gel	38.7	56	1.01
Calculation for 38% styrene	Calculation	38.000	55.550	1.00

Distance from Gun to Mold

NMMA Boat Manufacturing testing	Description	Distance from mold (inches)	Emissions	Modification factor (15" = 1.0)
28' Hull, 42% styrene resin	Average, 2 runs	36	23.3	1.35
18' Hull, 42% styrene resin	Average, 2 runs	27	20.7	1.20
Calculated for 15 inches		15	17.233	1.00
NMMA Boat Manufacturing testing				
28' hull, 35% styrene resin	Average, 2 runs	36	17.4	1.54
18' hull, 35% styrene resin	Average, 2 runs	27	14.8	1.31
Calculated for 15"		15	11.333	1.00
NMMA Boat Manufacturing testing				
28' Hull, gel coat	Average, 2 runs	36	53.7	1.19
18' Hull, gel coat	Average, 2 runs	27	50.1	1.11
Calculated for 15"		15	45.300	1.00

Dry-Material-Off-Mold

Emissions (% AS)	Emissions (relative to 6% off mold)
62.5	1.16
54.2	1.01
53.7203	1.00
Emissions (% AS)	Emissions (relative to 6% off mold)
27.1	1.52
17.5	0.98
16	0.90
17.8031	1.00

Laminate or Gel Coat Thickness

CFA Phase I testing (October 1995), resin sprayup	Description	Thickness (in.)	Emissions (% AS)	Emissions (relative to 70 mils)	Emissions (relative to 20 mils)
Average of 40 mils		40	26.04	1.06	
Average of 80 mils		80	24.00	0.98	
Calculation for thickness = 70 mils		70.000	24.510	1.00	
CFA Phase I testing (October 1995), gel coating	Description	Thickness (in.)	Emissions (% AS)	Emissions (relative to 70 mils)	Emissions (relative to 20 mils)
Average of 24 mils		24	47.49	1.94	0.891
Average of 18 mils		18	56.21	2.29	1.055
Calculation for thickness = 20 mils		20	53.303		
CFA hand lay-up	Description	Thickness (mils)	Emissions (% AS)	Emissions (relative to 70 mils)	
Average of 41 mils	Average	41	17.65	1.26	
Average of 88 mils	Average	88	11.73	0.84	
Calculation for thickness = 70 mils	Calculation	70.000	13.997		
EPA/RTI P2 Testing (June 1995), gel coating	Description	Thickness (in.)	Emissions (% AS)	Emissions (relative to 70 mils)	Emissions (relative to 20 mils)
		21	49.2		0.86
		20	57.6		1.01
		21	55.7		0.97
		20	54.9		0.96
		19	58.9		1.03
		19	60.2		1.05
		21	56.4		0.99
		20	59.2		1.04
		24	50.6		0.89
		24	52.7		0.92
		21	58.0		1.01
Calculation for thickness = 0.020	Calculation	20.000	57.15	>>>>>>>>>>	1.00

Cup Gel Time

CFA Phase I testing, resin sprayup	Description	Gel time (min)	Emissions (% AS)	Emissions (relative to 15-minute gel)
Average for 30 minutes	Slow gel	30	25.38	1.029
Average for 15 minutes	Fast gel	15	24.66	1.000
CFA Phase I testing, gel coating	Description	Gel time (min)	Emissions (% AS)	Emissions (relative to 15-minute gel)
Average for 20 minutes	Slow gel	20	52.30	1.01
Average for 10 minutes	Fast gel	10	50.78	0.99
Calculated average for 15 minutes	Calculated	15	51.540	1.00
CFA phase I testing, hand lay-up	Description	Gel time (min)	Emissions (% AS)	Emissions (relative to 15-minute gel)
Thin laminates-Slow gel average	Slow gel	30	19.32	1.21
Thin laminates-Fast gel average	Fast gel	15	15.98	1.00
Thick laminates-Slow gel average	Slow gel	30	12.42	1.18
Thick laminates-Fast gel average	Fast gel	15	10.56	1.00
All thicknesses, slow gel	Slow gel	30	15.95	1.21
All thicknesses, fast gel	Fast gel	15	13.23	1.00

Application Rate

CFA Phase I resin sprayup, 10/95	Description	Application rate (lb/min)	Emissions (% AS)	Emissions (relative to 3 lb/min rate)
Average for 4 lb/min	Fast application	4	22.71	1.000
Average for 2 lb/min	Slow application	2	27.33	1.203
Calculated for 4 lb/min	Calculated	4	22.710	1.000
CFA Phase I gel coating, 10/95	Description	Application rate (lb/min)	Emissions (% AS)	Emissions (relative to 2 lb/min rate)
Average for 4 lb/min	Fast application	4	51.84	1.012
Average for 2 lb/min	Slow application	2	51.24	1.000
Calculated for 2 lb/min	Calculated	2	51.244	1.000

Air Temperature

Dow filament winding, from 1997 report (w/THC)	Description	Temperature (F)	Emissions (% AS)	Average (% AS)
1	Low temperature	73	14.86	
4	Low temperature	73	14.3	
7	Low temperature	73	24.12	
8	Low temperature	73	10.08	
10	Low temperature	73	11.69	
12	Low temperature	73	9.47	
13	Low temperature	73	17.08	
14	Low temperature	73	21.74	
17	Low temperature	73	11.09	14.937
2	High temperature	85	17.5	
3	High temperature	85	12.12	
5	High temperature	85	16.38	
6	High temperature	85	21.07	
9	High temperature	85	17.76	
11	High temperature	85	13.53	
15	High temperature	85	10.65	
16	High temperature	85	18.95	
18	High temperature	85	24.51	16.941

Air Velocity (above 40 fpm)

EPA/RTI Pollution Prevention testing, June 1995	Description	Velocity (ft/min)	Emissions (% AS)	Emissions (relative to 100 ft/min)
Pilot A2 (6 runs)	Low velocity	49	57.4	0.98
Pilot A1 (6 runs)	High velocity	123	59.2	1.01
Calculation for V= 100 ft/min	Calculation	100	58.6	1.00
CFA Phase I Testing, Resin Sprayup	Description	Velocity (ft/min)	Emissions (% AS)	Emissions (relative to 100 ft/min)
High velocity (100 fpm)	Average, 10 runs	100	25.26	1.00
Low velocity (50 fpm)	Average, 10 runs	50	24.78	0.98
CFA Phase I Testing, Gel coating	Description	Velocity (ft/min)	Emissions (% AS)	Emissions (relative to 100 ft/min)
High velocity (100 fpm)	Average, 10 runs	100	50.62	1.00
Low velocity (50 fpm)	Average, 10 runs	50	52.46	1.04

Air Velocity (below 40 fpm)

Pultrusion Phase II	Description	Velocity (ft/min)	Emissions (lb/hr)	Emissions (relative to 100 ft/min)
A1	Single run	0	0.38	0.41
F	Single run	15	0.49	0.53
J	Single run	100	0.93	1.00
RTI Bench-scale 1994	Description	Velocity (ft/min)	Emissions (lb/hr)	Emissions (relative to 100 ft/min)
Dynatron Bondo Resin	Paint lid	10	2.35	0.72
Dynatron Bondo Resin	Paint lid	50	2.8	0.86
Dynatron Bondo Resin	Paint lid	70	3.1	0.95
Dynatron Bondo Resin	Paint lid	210	3.9	1.19
Calculation for V=100 ft/min	Calculation	100	3.3	1.00
RTI Bench-scale 1994	Description	Velocity (ft/min)	Emissions (lb/hr)	Emissions (relative to 100 ft/min)
Ashland Resin	Paint lid	5	5.7	0.97
Ashland Resin	Paint lid	15	5.8	0.98
Ashland Resin	Paint lid	50	5.9	1.00
Ashland Resin	Paint lid	120	5.9	1.00
Ashland Resin	Paint lid	210	5.8	0.98
Calculation for V=100 ft/min	Calculation	100	5.9	1.00

Styrene Suppressant

EPA/RTI Pollution Prevention Testing, June 1995	Description	Suppressant amount (%)	Emissions (% AS)	Emissions (relative to no suppressant)
Styrene suppressant	43.5% sty, 17 minute gel	0.7	10.6	*****
Styrene suppressant plus wax	43.3% sty, 17 minute gel	1.7	10.6	*****
Calculation for styrene suppressant	Calculated, 38.3% sty, 20 minute gel	0.7	9.664	0.552
Styrene suppressant plus wax	Calculated, 38.3% sty, 20 minute gel	1.7	9.699	0.554
No suppressant (baseline resin)	38.3% sty, 20 minute gel	0	17.5	1.00